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TESTS
OF A POWDERED-COAL PLANT

A REPORT OF INVESTIGATIONS AT THE POWER PLANT OF THE ST. JOSEPH LEAD CO., RIVERMINES, MO.

BY

HENRY KREISINGER, JOHN BLIZARD
C. E. AUGUSTINE, and B. J. CROSS

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TESTS OF A POWDERED-COAL PLANT.

By HENRY KREISINGER, JOHN BLIZARD, C. E. AUGUSTINE, and B. J. CROSS.

INTRODUCTION.

This paper gives the results of tests of the pulverized-coal plant of the St. Joseph Lead Co., Rivermines, Mo. The tests, which comprised two boiler tests, six dryer tests, and eight mill tests, were made by the fuel section of the Bureau of Mines, the Combustion Engineering Corporation, and Stone & Webster (Inc.). The boiler tests were made on two Stirling boilers, each having 7,688 square feet of heating surface and designated as boilers No. 8 and No. 9. Boiler test 1 covered a period of 48 hours and was run at 200 per cent of rating. Test 2 was made on both boilers, lasted nine days, and was run under actual operating-load conditions, the load varying from 100 to 200 per cent of rating.

The coal used in these boiler tests was weighed as delivered to the preparation plant and before being pulverized. As the coal was passing through this plant, tests were also made of the drying and pulverizing units for the main object of determining the capacity of these units and the power they consumed. During each of the drier and mill tests 100 to 300 tons of coal was dried or pulverized. The tests could not be made in one period of continuous operation on account of a lack of storage capacity. Therefore each test was made in several operating periods between which the equipment was idle, sometimes for several hours. For this reason the results of the tests of the preparation units are not as good as they would have been if each test had been made in one continuous operation. Bituminous coal from southern Illinois, of good quality for that district, was used. It was shipped as screenings, and the part delivered to the powdered-coal plant contained little slack.

PERSONNEL.

The following men took an active part in the tests: Henry Kreisinger, John Blizard, C. E. Augustine, B. J. Cross, G. F. Weaton, J. Pope, R. J. Hinch, T. Kruger, W. L. Tebbs, A. Hoffman, H. Klotz, and G. W. Clendon.

SUMMARY OF RESULTS OF TESTS.

STEAMING TESTS.

The summary of the principal results of all tests is given in Tables 1, 2, and 3. Table 1 gives the results of the two steaming tests. Test 2 is divided into two parts; the first part covered five days, and was made with coal that had been dried before being pulverized; the second part lasted four days, and was made with undried coal. Two thermal efficiencies were computed, namely: 1, The overall thermal efficiency, which is the ratio of the heat absorbed by the boiler to the heat in the coal supplied to the preparation plant; and 2, the thermal efficiency of the boiler only, which is the ratio of the heat absorbed by the boiler to the heat in the coal delivered to the boiler. Neither efficiency includes the power used in preparing and conveying the coal.

The overall efficiency (1) is the smaller because of the coal burned in the drier furnace, the loss of coal dust in drying, the loss of coal dust discharged from the mill vents, and the loss of heat in the pyrites removed from the mills; but it was only about 1.5 per cent less with dried coal, and negligibly less with undried coal. The overall thermal efficiency is almost identical with that obtained in tests of No. 9 boiler in January, 1921, made by engineers of Stone & Webster (Inc.). A summary of the results of these tests is given in Table 4 for comparison. The results of test 1 are comparable with test 6 of Table 4, and the results of the first part of test 2 with dried coal compare with test 2 of Table 4.

TABLE 1.—*Summary of results of boiler tests.*

Test number	1	[1] 2	[2] 2
Duration ... hours	48	119.22	93.28
Condition of coal when burned	Dried.	Dried.	Undried.
Rating ... per cent	202	155	155
CO_2 ... do	12.9	13.7	13.6
Temperature of flue gas ... ° F	666	561	567
Temperature of superheated steam ... ° F	546	525	534
Overall thermal efficiency, in per cent of heat in coal supplied to preparation plant	72.6	77.3	78.2
Thermal efficiency of boiler only in per cent of heat in coal supplied to boilers	74.4	78.8	78.4

[1] First 5 days.

[2] Last 4 days.

TABLE 2.—*Summary of results of mill tests.*

Condition of coal	Dried.	Undried.
Capacity ... tons per mill-hour	5.6	4.2
Power required per ton ... kw. h	13.9	18.5
Moisture in coal as pulverized ... per cent	4.9	6.1
Coal through 100-mesh screen ... do	94.9	95.0
Coal through 200-mesh screen ... do	75.0	76.0

TABLE 3.—*Summary of results of drier tests.*

Capacity per hour ... tons	15.62
Moisture content before drying ... per cent	7.53
Moisture content after drying ... do	4.87
Power required per ton of coal ... kw. h	1.68
Coal used in drying, per cent of coal dried	1.29

TABLE 4.—*Summary of results of previous boiler tests made by Stone & Webster in January, 1921.*

Test number	3	2	5	6
Duration ... hours	21.3	22.5	26.0	19.75
Condition of coal when burned	Dried.	Dried.	Dried.	Dried.
Rating ... per cent	103	152	181	205
CO_2 ... do	15.4	14.5	12.3	12.9
Temperature of flue gases ... ° F	465	528	586	609
Temperature of superheated steam ... do	494	500	501	520
Overall thermal efficiency, in per cent of heat in coal supplied to preparation plant	77.8	77.5	73.8	72.9

POWER USED BY PULVERIZING MILLS.

Table 2 shows that with the dried coal the output of the mills was 5.6 tons per hour, and with the undried coal only 4.2 tons. The mills are rated at 6 tons per hour each and would probably pulverize that much when operating continuously. With the dried coal the power consumption was 13.9 kw. hours per ton, whereas with the undried coal it increased to 18.5 kw. hours, an increase of 4.6 kw. hours.

DRIER TESTS.

Table 3 gives the principal results of six drier tests. The drier dried 15 to 16 tons of coal per hour and reduced the moisture content by about 3 per cent. Only a low fire was kept in the furnace; had a hotter fire been carried more moisture would have been driven from the coal, but obviously more coal would have been used as drier fuel. It seems that only the surface moisture need be removed in the drier to enable the coal to pulverize easily. The undried coal is not difficult to burn. To dry 1 ton of coal, 25 pounds of coal was burned and 1.7 kw. hours used to operate the drier and necessary conveyors; but to pulverize and convey the dried coal required 4.7 kw. hours less than to pulverize and convey the undried coal. Thus the energy saved in preparing and conveying 1 ton of undried coal was equivalent to 25 pounds of coal, and the energy lost was 3 kw. hours. On the assumption that 2 pounds of coal was required to generate 1 kw. hour, the energy lost is equivalent to 6 pounds of coal. The preparation energy saved per ton by not drying is therefore 19 pounds of coal per ton, or about 1 per cent; but the net gain is only about 0.7 per cent, energy saved per ton by not drying is, therefore, 19 pounds of coal was dried and a part of the heat used to heat the coal in the drier was available for raising steam.

THE BOILER PLANT.

BOILERS AND FURNACES.

There were two Stirling boilers, each having 7,688 square feet of heating surface, set singly and connected by steel breeching to a brick stack 200 feet high. The furnaces were of the Lopulco

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design and each was equipped with two duplex, round-nozzle burners. At the discharge ends the nozzles were cut at an angle of 45°, with the long lip next to the front wall and slightly curved away from it, as shown in Figure 1. The object of this modification of the nozzle was to spread the stream of coal and to direct it slightly away from the front wall. Each burner was supplied with coal from a separate feeder connected to it by a 3½-inch pipe. About 20 feet of these feeder pipes was in a horizontal position. Air was supplied to the feeders under a pressure of 8 to 14 inches of water by one No. 7 Sturtevant steel pressure blower, driven by a 30-h. p. 3-phase a. c. motor. The feeders were driven in pairs by 3-h. p. a. c. motors, the speed being controlled by Reeves transmissions.

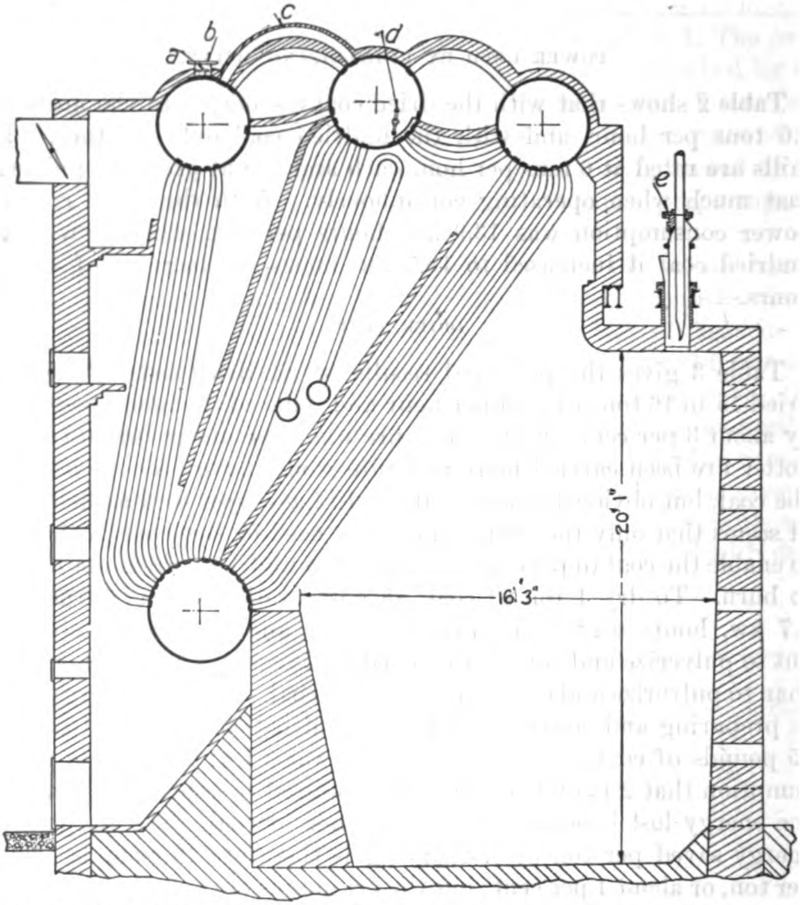

FIGURE 1.—Side elevation of Stirling boiler. *a*, Feed water; *b*, steam; *c*, auxiliary steam tubes; *d*, Weaton continuous blow-down; *e*, Lopulco duplex burners.

The front furnace walls were of the original Lopulco design, with the corners cut off and incased in cast-iron plates. There were 27

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air inlets through the front walls, with slanting cast-iron doors hinged at the top. There were also four cleaning-out doors on a level with the boiler-room floor. The bottom of the furnace was about 18 inches below the boiler-room floor, sloping up toward the cleaning-out doors. All the walls were built solid, with no air ducts for cooling.

COAL DRIERS AND PULVERIZERS.

The preparation plant consisted of two 6-ton Raymond mills, one Ruggles-Cole coal drier, one Jeffrey roll crusher, one magnetic tramp-iron separator, and the necessary conveyors to move the coal.

Data on the equipment of the plant are given below:

Data on pulverized-coal plant of St. Joseph Lead Co.

Boilers:	
Type, Stirling; class, M–28, single.	
Number of steam drums	3
Diameter of steam drums ... inches	42
Length of drum shells ... feet	15.7
Number of mud drums	1
Diameter of mud drums ... inches	48
Length of mud-drum shell ... feet	15.7
Number of tubes in first bank	168
Number of rows of tubes in first bank	6
Number of tubes in second bank	140
Number of rows in second bank	5
Number of rows in third bank	5
Number of tubes in each row in all three banks	28
Number of circulating tubes between first and second steam drums	84
Number of circulating tubes between second and third steam drums	28
Outside diameter of all tubes ... inches	3¼
Total heating surface ... square feet	7,688
Condition of boilers: Boilers examined internally one month after test and no scale or mud deposit found anywhere on heating surfaces. Boilers were apparently clean during tests.	
Superheaters:	
Type, Babcock & Wilcox.	
Number of elements	111
Number of outside elements	56
Number of inside elements	55
Outside diameter of tubes ... inches	2
Total heating surface of superheater ... square feet	878
Furnaces:	
Type, powdered coal, Lopulco design.	
Number of burners in each furnace	4
Type of burners—3½-inch diameter, round nozzle, duplex.	
Height of furnace below arch ... feet	20.4
Height of bridge wall above bottom of furnace ... do	10
Length of furnace at bottom ... do	14
Extreme length of furnace at top of bridge wall ... do	16

Width of furnace	feet	14
Number of air openings in front wall		27
Size of air inlets	inches	9 by 9
Number of cleaning-out doors		4
Size of cleaning-out doors	inches	15½ by 20
Total combustion space	cubic feet	4,000

Conditions of furnace lining before tests:

Side walls on No. 8 boiler eroded for 4 inches about half way up.

Side walls on No. 9 boiler eroded for 9 to 12 inches half way up.

Size of openings in passes:

	Boiler No. 8.	Boiler No. 9.
First baffle	57 inches	54 inches
Second baffle	32 inches	32 inches
Third baffle	31 inches	33 inches

Pulverizing mills:

Number and size of mills, 2; Raymond 6 roll.

Capacity	tons per hour	6
Speed of spider	r. p. m.	113

Motors driving mills—75-h. p., a. c., 3-phase, 440-volt, 88-amp., 860 r. p. m.

Motors driving mill blowers—40-h. p., a. c., 3-phase, 440-volt, 48.5 amp., 1,146 r. p. m.

Drier:

Type—Ruggles-Cole.

Capacity	tons per hour	16
Length of drier	feet	44.75
Diameter of outside shell	inches	81
Diameter of inside shell	inches	32
Inclination of drier	inches in 45 feet	18
Speed of drier	r. p. m.	6

Motor for driving drier—40-h. p., a. c., 3-phase, 440-volt, 50-amp., 855 r. p. m.

Drier furnace:

Length	feet	7
Width	do	6
Average height above grate	do	6
Height of grate above ash-pit floor	inches	23

Type of grate—herringbone; ½-inch air spaces.

Length of flue from furnace to drier	feet	5½
Outside diameter of flue	inches	38
Thickness of brick lining of flue	do	4½

Drier exhauster:

Type—Clarage Fan Co.; S. P. No. 60, belt driven.

Speed	r. p. m.	415

Motor driving drier exhauster (also driving drier coal-feeder), 7½-h. p., a. c., 3-phase, 440-volt, 10-amp., 855 r. p. m.

Coal crusher:

Type—Jeffrey, roll.

Motor driving crusher (also driving conveyor belt for coal to crusher), 30 h. p., a. c., 3-phase, 440-volt, 38.5-amp., 860 r. p. m.

METHOD OF CONDUCTING BOILER TESTS.

Since weighing the coal as it was supplied to the boilers was impossible, the coal was weighed as delivered to the preparation plant. About three or four hours before a test started all of the bins and

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conveyors in this plant were cleaned out, and the weighing of coal for the test was begun, the coal being delivered to the storage bin in front of the drier. After about 20 tons were weighed, the drier was started and the dried coal delivered to the mill bins ready to be pulverized. The pulverized coal in the feeder bins was watched, and when the bins were nearly empty the weighed coal was started through the pulverizing mills and the test was begun.

At the time of starting the test the height of coal in the feeder bin was about 2 feet above the feeder screws. This coal occupied about 20 cubic feet per bin, or 40 cubic feet per boiler. Less than a ton of coal, therefore, was in the bins of each boiler when a test began, and the possible error in estimating the amount of coal in the bin at the start of the test was only a fraction of a ton.

A few hours before closing the test the bins, the drier, and the conveyors in the preparation plant were again cleaned out, except that a reserve of about 5 tons was left in one of the mill bins. When toward the close of the test the coal in any one of the four feeder bins was running lower than in the others, the reserve coal was pulverized and delivered to the bin containing the least coal. Additional regulation of the height of coal was obtained by adjusting the speed of the feeder screws, speeding up the feeders in the bins with the greater coal contents and retarding those in the bins with the smaller supply. Thus at the close of the test the coal in all of the bins was very nearly at the same height as it was when the test was started.

WEIGHING THE COAL.

The coal was weighed on a suspension scale in lots of about 1,100 pounds. The scale was placed under the discharge from a large silo-plant bin, and the discharge from the scale hopper was placed over a belt conveyor delivering coal to the pulverizing plant. After the coal was weighed it was discharged slowly from the scale hopper to the belt conveyor, which delivered it to the crusher and magnetic separator. The belt conveyor, crusher, and magnetic separator were run all the time the coal was being weighed, although the coal was running through only when it was being discharged from the scale hopper. Therefore the power used by the belt conveyor, crusher, and the magnetic separator was about three times as much as it was under ordinary operating conditions.

SAMPLING THE COAL.

Separate samples of coal were collected for every 50 tons at three points along the path of travel from the coal-weighing scale to the feeder bins. The first sample was collected at the feeder to the drier. Here the coal had been crushed to one-half-inch size, and as it passed through the feed in a uniform stream the chances of obtaining a fair sample were good.

Another sample was collected at the mill bins after the coal had passed through the drier.

A third sample was collected in the feeder bins by inserting a three-fourths-inch tube into the bin through a hole near the front of the feeder and close to the feeder screw. It seems that the sampling hole was too close to the front of the feeder bin, and at times the condensation of steam on the front wall of the bin increased the moisture content of the coal from which the sample was taken.

The coal samples taken at the feeder to the drier when the drier was running and the samples taken at the mill bins when the coal was not dried were used in computing the results of the boiler tests, because these samples represented the coal as it was weighed. When the coal was not dried the drier was by-passed and the coal was conveyed directly to the mill bins.

The coal samples were reduced to about 10 pounds, and each 10-pound sample placed in two air-tight shipping cans. One of these cans was sent to the Bureau of Mines chemical laboratory at Pittsburgh, Pa., and one to the laboratory of the St. Joseph Lead Co. The analyses made by the bureau were used in computing the tests.

MEASURING THE FEED WATER.

The volume of feed water was measured in two tanks holding approximately 4,330 pounds of water at 180° F. The top of each tank was reduced by a cone to a neck having a diameter of about 13 inches, with a catch that drained the overflow water away. At each filling the tanks were filled to overflow. The discharge pipe was fitted to the bottom of the tanks so that they could be emptied completely. Each tank was calibrated to determine the weight of water it contained at different temperatures; whenever a tank was filled the temperature of the water was measured and the weight of water was determined from the calibration curve. The measured water was discharged into another large tank, from which it was pumped to the boilers.

WEIGHING THE BLOW-OFF WATER.

The feed water was bad, and caused excessive priming in the boilers unless they were frequently blown off. For this reason George F. Weaton, chief engineer for the power plants, devised a method of continually blowing off the boilers. The quantity of water blown off was regulated according to the concentration of the solids in the water in the boiler; this concentration was continually indicated by a specially devised, simple but effective instrument attached to the blow-off pipe of each boiler. The boiler attendant watched this instrument in the same way that he watched his pressure gage, and kept the concentration of solids in the boiler water at a safe point without wasting too much hot water. The blow-off water was taken from the center drum as shown in Figure 1, because at this point the concentration of solids was highest.

During the tests the blow-off water was cooled by passing through coils immersed in cooling water, then discharged into a weighing tank and weighed. The weight of the blow-off water was deducted from the feed water, but the amount of heat the blow-off water absorbed was credited to the boiler.

The pump leakage was caught, and its weight was deducted from the weight of the feed water.

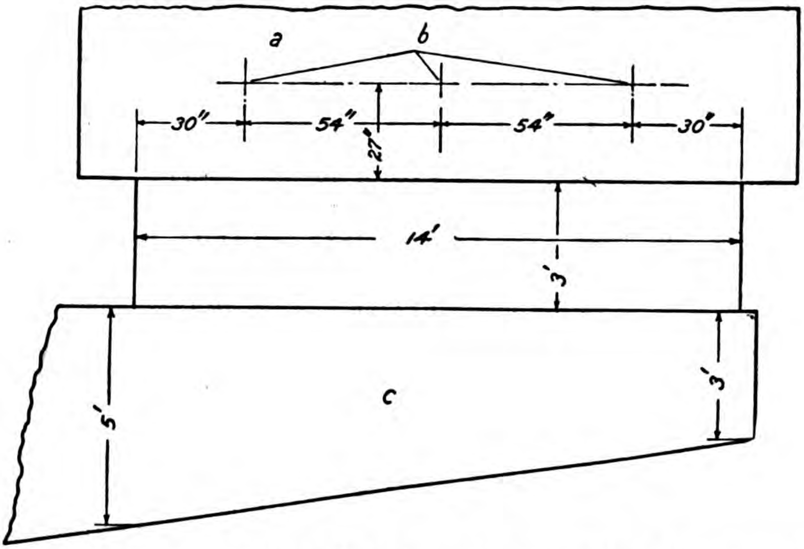


FIGURE 2.—Boiler No. 9, St. Joseph Lead Co. *a*, Boiler; *b*, position of thermocouples and gas-sampling pipes; *c*, flue.

FLUE-GAS ANALYSIS.

Flue gases were sampled at three points in the uptake of each boiler. These points are shown in Figures 2 and 3. The samples taken in the center of the uptake were collected over one-hour periods. Samples from the two side points were collected and analyzed every 15 minutes to determine as rapidly as possible whether the coal and air supply was properly adjusted. The composition of the central sample is given in the results of the tests.

FLUE-GAS TEMPERATURE.

Copper-constantan couples and a potentiometer were used to measure the temperature of the flue gases in the uptake of each boiler at the same three points where gas samples were collected. A mercury thermometer was also inserted 9 inches in front of the central thermocouple; it indicated a lower temperature than the couples indicated because it was nearer the upper edge of the stream (see Fig. 3), which, as shown by means of a survey with thermocouples, were cooler than the center. The results of these temperature surveys are shown in Figures 4, 5, 6, and 7.

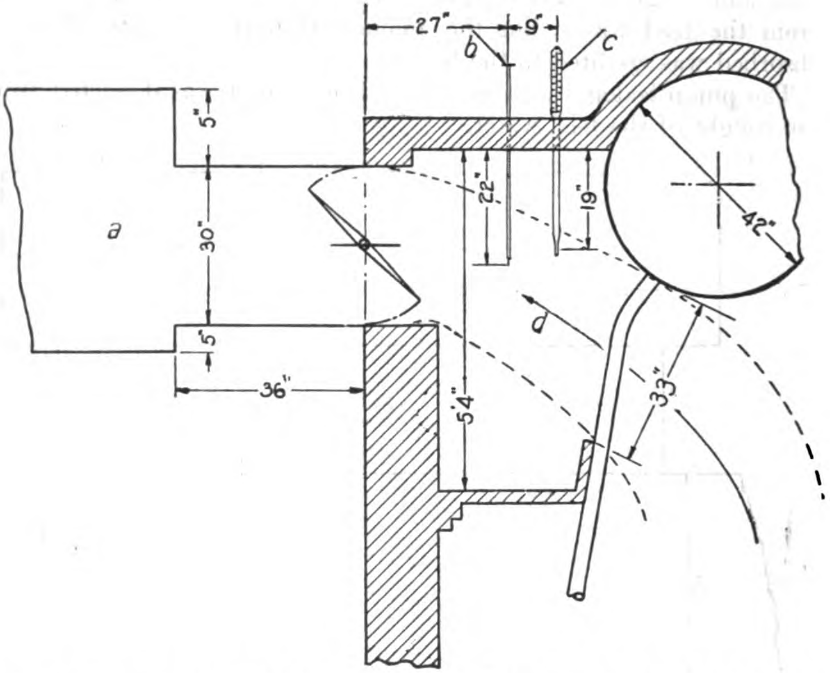


FIGURE 3.—Section of gas outlet. *a*, Flue; *b*, thermocouples and gas sampler; *c*, thermometer; *d*, path of gases.

The three thermocouples were placed in the center of the stream and the average of their temperatures was taken as the temperature of the gases leaving the boiler.

TEMPERATURE OF FEED WATER AND SUPERHEATED STEAM.

Mercurial thermometers inserted in thermometer wells were used. They were calibrated at the Bureau of Mines physics laboratory for an immersion of 4 inches, and therefore no stem corrections were needed.

OTHER OBSERVATIONS.

Other observations customary in a properly conducted boiler test were made with suitable instruments in a thorough manner.

OPERATION OF SOOT BLOWERS.

On test 1 the soot blowers were operated every six hours and on test 2 they were operated every four hours. In Plate I the soot-blowing periods are indicated by the dots at the bottom of the charts. (Page 14.)

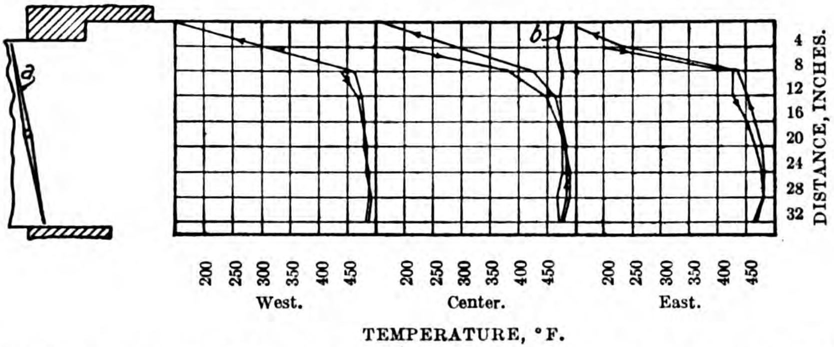


FIGURE 4.—Temperatures in uptake of boiler No. 9. Average rating, 102 per cent. *a*, Damper; *b*, stationary couple.

METHOD OF CONDUCTING DRIER AND MILL TESTS.

The drier and mill tests were secondary to the boiler tests, and both the drier and the mills were run for short periods to prepare the coal as needed by the boilers. At times the drier was used for periods of only 45 minutes. When the mill bins were nearly filled, the feed of coal into the drier was stopped; but the drier and conveyors had to be run about 20 to 30 minutes longer in order to be sure that no coal remained in the drier, and thus eliminate danger of a fire in the drier. When the drier was started again it took 10 to 20 minutes to fill, and for this reason the sum of the operat-

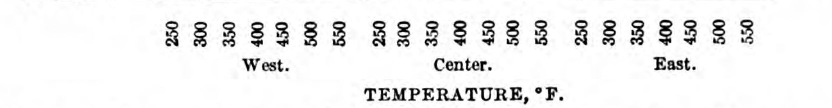


FIGURE 5.—Temperatures in uptake of boiler No. 9. Average rating, 152 per cent. *a*, Damper; *b*, stationary couple.

ing periods was much longer than if the drier had been operated continuously in one period. This matter was discussed with Mr. Weaton, and he recommended that for each operating period 40 minutes be deducted from the sum of these periods. This manner of computing the drier tests brings the results closer to what they would have been if the drier had been operated almost continuously.

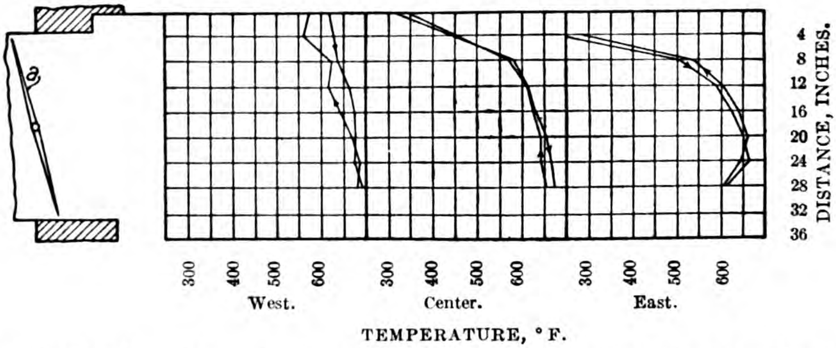


FIGURE 6.—Temperatures in uptake of boiler No. 9. Average rating, 202 per cent. *a*, Damper.

The power used in operating the different units of the preparation plant was determined from the ampere readings. Each motor had an ammeter in one of the three phases of the circuit, which was read during the operation of the units. Mr. Weaton went over his past records of power consumption and recommended a mean power factor of 0.8, which gives

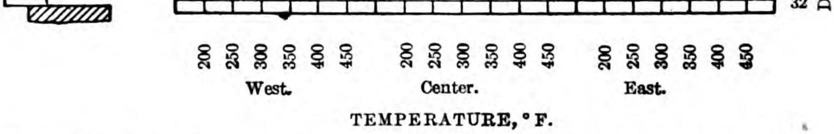


FIGURE 7.—Temperatures in uptake of boiler No. 8. Average rating, 116 per cent. *a*, Damper; *b*, stationary couple.

$$\text{Power in watts} = 0.8\sqrt{3}\, e\, i$$

where i = amperes per terminal and e = average volts between terminals.

The voltage at the motors was 460 and was constant; therefore, the power in kilowatts was equal to 0.64 times the amperes. This method of computation gives the power correct to within 2 or 3 per cent.

For the drier tests the following observations were taken:

1. Temperature of gases entering drier.
2. Percentage of CO_2 in gases entering drier from furnace.
3. Temperature of gases leaving drier.
4. Temperature of coal leaving drier.
5. Draft in flue to drier.
6. Draft in flue from drier.

RESULTS OF BOILER TESTS.

The averages of the data and the results of the two boiler tests are given in Table 5.

TABLE 5.—*Results of boiler tests at Rivermines, Mo.*

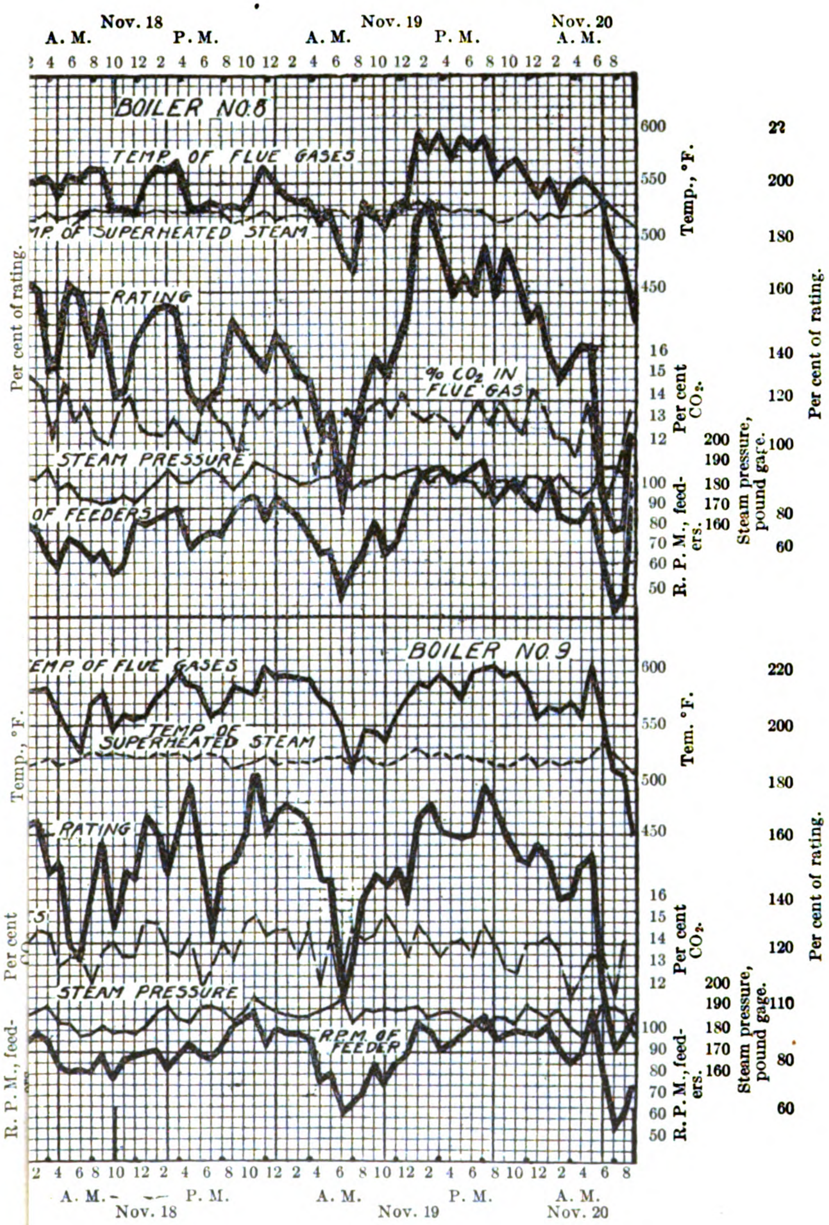
1. Test number	1	2	2	2
2. Part of test	Entire test.	First 5 days	Last 4 days.	Entire test.
3. Boiler number	8	8 and 9	8 and 9	8 and 9
4. Duration ... hours	48.00	119.22	93.28	212.50
5. Condition of coal when pulverized	Dried.	Dried.	Undried.	....
6. Total coal used ... pounds	297,010	1,069,080	828,880	1,897,950
7. Coal used in drier ... do	4,540	11,280	0	11,280
8. Coal used in drier ... per cent of total	1.5	1.1	0	0.6
9. Pyrites taken from mills ... pounds	1,407	3,056	2,794	5,850
Analysis of coal, as received:				
10. Coal sample taken	To drier.	To drier.	To mills.	....
11. Moisture ... per cent	8.4	7.0	6.2	6.6
12. Volatile matter ... do	32.8	31.3	32.2	31.7
13. Fixed carbon ... do	48.3	49.4	48.4	49.0
14. Ash ... do	10.5	12.3	13.2	12.7
Ultimate analysis, as received:				
15. Moisture taken out in drier ... do	3.2	2.1	0	1.2
16. Hydrogen ... do	5.0	4.9	4.9	4.9
17. Carbon ... do	64.7	65.3	64.5	65.0
18. Nitrogen ... do	1.3	1.4	1.3	1.3
19. Oxygen ... do	12.9	11.8	13.1	12.3
20. Sulphur ... do	2.4	2.2	3.0	2.6
21. Ash ... do	10.5	12.3	13.2	12.7
22. Calorific value, as received ... B. t. u.	11,600	11,530	11,510	11,520
Size of pulverized coal:				
23. Coal through 200-mesh screen ... per cent	78	73	76	74
24. Coal through 100-mesh screen ... do	95	95	95	95
Ash and refuse:				
25. Carbon in furnace slag ... do	0	0	0	0
26. Carbon in flue dust ... do	11.2	7.5	7.5	7.5
27. Carbon in refuse ... per cent of coal	1.2	1.0	1.0	1.0
Flue gases and air:				
28. Carbon dioxide, by volume ... per cent	12.9	13.7	13.6	13.7
29. Oxygen, by volume ... do	6.2	5.3	5.4	5.3
30. Carbon monoxide, by volume ... do	0.0	0.02	0.04	.03
31. Excess air ... do	38	32	32	32
32. Temperature of flue gases ... ° F	666	561	567	564
33. Temperature of boiler room ... ° F	72	76	79	77
Draft, inches of water:				
34. In furnace	0.05	0.06	0.05	0.06
35. In uptake	0.59	0.30	0.32	0.31
36. In stack	1.00	1.20	1.20	1.20
Pressures, above atmosphere:				
37. Steam to superheater ... pounds per sq. inch	186	187	186	187
38. Steam from superheater ... do	184	185	184	185
39. Air pressure at feeders ... inches of water	6.0	7.2	10.1	8.5
Steam and water:				
40. Total water fed to boilers ... pounds	2,292,187	8,784,609	6,873,497	15,658,106
41. Total blow-off water ... do	96,966	428,158	333,365	761,523
42. Total water evaporated ... do	2,195,221	8,356,451	6,540,132	14,896,583
43. Water evaporated per pound coal entering preparation plant ... pounds	7.39	7.82	7.89	7.85
44. Blow-off water per pound of coal entering preparation plant ... pounds	0.33	0.40	0.40	0.40
45. Temperature of superheated steam ... °F	546	525	534	529

TABLE 5.—*Results of boiler tests at Rivermines, Mo.*—Continued.

Steam and water—Continued.				
46. Temperature of saturated steam...........°F..	382	382	382	382
47. Temperature of feed water.................°F..	194	185	188	186
Heat absorption:				
48. Heat absorbed by boiler and superheater per pound of steam......................B. t. u..	1,132	1,129	1,131	1,130
49. Heat absorbed per pound of blow-off water, B. t. u.....................................	193	202	198	200
50. Heat absorbed by steam per pound of coal entering preparation plant................B. t. u..	8,360	8,830	8,920	8,870
51. Heat absorbed by blow-off water per pound of coal entering preparation plant.......B. t. u..	65	80	80	80
52. Total heat absorbed per pound of coal....do....	8,425	8,910	9,000	8,950
Rates:				
53. Heat absorbed by boiler and superheater per square foot of boiler heating surface per hour, B. t. u..	6,780	5,200	5,210	5,200
54. Boiler horsepower developed by boiler and superheater..................................	1,557	2,390	2,390	2,390
55. Per cent of rating of boiler developed by boiler and superheater...............................	202	155	155	155
56. Coal burned per hour.................pounds..	6,190	8,970	8,890	8,930
57. Coal burned per hour per cubic foot of combustion space...........................pounds..	1.55	1.12	1.11	1.12
58. Coal per revolution of feeders............do....	0.26	0.27	0.22	0.24
Heat balance in per cent of heat in coal supplied to preparation plant:				
Preparation plant—				
59. Heat in coal burned in dryer.....per cent..	1.5	1.1	0.0	0.6
60. Heat in coal dust discharged with gases from dryer and mills..................per cent..	0.7	0.7	0.2	0.5
61. Heat in pyrites removed from mill...do....	0.2	0.1	0.1	0.1
Boilers and furnaces—				
62. Heat absorbed by boilers............do....	72.6	77.3	78.2	77.7
63. Heat carried away by dry flue gases..do....	15.4	12.1	12.1	12.1
64. Heat carried away by steam in products of combustion.....................per cent..	5.1	4.9	4.9	4.9
65. Heat loss in CO in flue gases.........do....	.0	.1	.2	.1
66. Heat loss in carbon in flue dust.......do....	1.5	1.3	1.3	1.3
67. Heat loss by radiation...............do....	2.6	2.8	2.8	2.8
68. Errors and "unaccounted for" heat..do....	.4	−0.4	0.2	−0.1
Heat balance in per cent of heat in coal supplied to boilers:				
69. Heat absorbed by boilers ....per cent..	74.4	78.8	78.4	78.6
70. Heat carried away by dry flue gases......do....	15.8	12.3	12.1	12.2
71. Heat carried away by steam in products of combustion............................per cent..	5.2	5.0	4.9	5.0
72. Heat loss in CO and carbon in flue dust...do....	1.5	1.4	1.5	1.4
73. Heat lost by radiation..................do....	2.7	2.9	2.8	2.8
74. Errors and "unaccounted for" heat......do....	0.4	−0.4	0.3	0.0

Test 2 has been divided into two parts: Part 1 lasted five days and was made with dried coal; part 2 lasted four days and was made with undried coal. The results are based on the quantity and quality of coal supplied to the preparation plant. But the heat content of the steam from the moisture driven out from the coal in the drying process is not included in the heat balance, and therefore the item giving the percentage of heat carried away by steam in the products of combustion included only the heat content of the steam formed from the moisture which was left in the coal after drying and that formed by burning hydrogen. For this reason, under ultimate analysis of the coal "to drier" the moisture evaporated in the drier (item 15) is given as a separate item totaling, with the remaining constituents, 100 per cent. The remaining constituents (items 16 to 21) are those of the coal from the drier.

Item 62, the percentage of heat absorbed by the boilers, is the overall thermal efficiency based on the heat in the coal delivered to the preparation plant.



39039°—23. (Face p. 14.)

Item 60, the heat loss in coal dust discharged with the drier gases and through the air vents in the air-separation system of the mills, has been estimated. Deposits of coal dust on the roof of the preparation plant showed that this loss existed, and although there may be an error in estimating it, yet as the loss itself is comparatively small, the error does not affect the results appreciably.

The loss due to radiation is also estimated, but it is believed that these estimated values are correct within 0.2 or 0.3 per cent.

The efficiency on test 1 is somewhat low on account of high flue-gas temperatures caused by slag accumulating on the front row of the boiler tubes. This slag accumulation started at the bridgewell and gradually rose until at the end of the test it reached within 3 or 4 feet of the first steam drum, so that about 74 per cent of the spaces between the tubes on the slagged portion were closed. Part of the heating surface in the first bank of tubes was thus rendered ineffective and caused the flue gases to leave the boiler at a temperature about 40° F. higher than it would have been had the tubes not slagged over. This lower flue-gas temperature would have reduced the flue-gas losses and increased the efficiency by about 1 per cent.

The slag accumulates on the tubes when the boiler is operated continuously at high rating. Later work showed that slag did not accumulate on the tubes to a troublesome extent, even when the boilers were operated at high rating, if the soot blowers were used every four hours.

At the end of boiler test 2, which lasted nine days, there was practically no accumulation of slag on the tubes, and consequently the flue-gas temperatures remained normal.

GRAPHIC LOG OF BOILER TESTS.

Figure 8 and Plate I present graphically the hourly averages of the principal data of the two boiler tests. The "rating" was computed from the flow-meter reading and is correct within about 3 per cent. These graphic logs show that the feeder revolutions, the rating, the flue-gas temperature, and the superheat of steam rise and fall together.

RELATION BETWEEN RATING AND FLUE-GAS TEMPERATURE IN TEST 2.

Figure 9 shows the variation of flue-gas temperature with rating for boiler No. 9. This figure was plotted from the flow-meter readings. Inasmuch as practically no slag accumulated on the tubes during test 2, the curve shows the true relation under normal conditions.

LENGTH OF FLAMES.

In test 1 of boiler No. 9, at the average rating of 202 per cent, the flames on the average reached to within 3 feet of the bottom of the furnace. At the top they could be seen passing practically all the time through the first pass and entering the second bank of tubes.

In test 2 the flames reached on the average to within 3 feet of the furnace bottom, but at the top they passed through the first pass only when the rating was close to 200 per cent or when the excess air was low. Generally when more load was put on the boiler the fireman speeded up the feeders and then adjusted the draft, and while this adjustment was being made the furnaces were operated with low excess air.

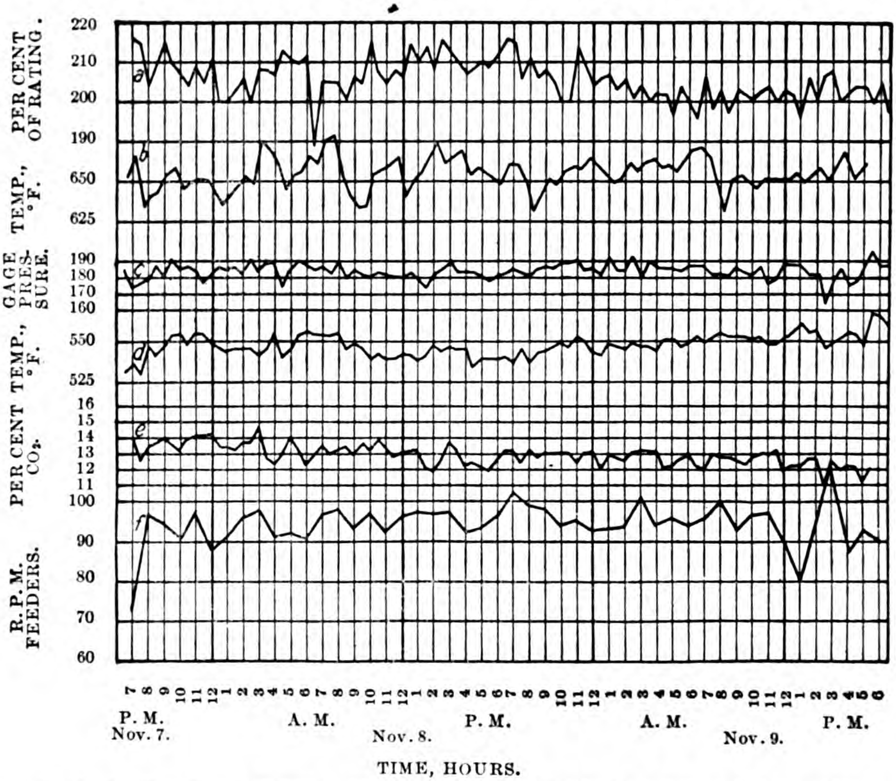


FIGURE 8.—Graphic log of test 1, boiler No. 9. *a,* Rating by flow meter; *b,* temperature of flue gases; *c,* steam pressure; *d,* temperature of superheated steam; *c,* percentage of CO_2 in flue gases; *f,* revolutions per minute of feeders.

CONDITION OF SLAG AT THE BOTTOM OF FURNACES.

In boiler test 1 during the first 12 hours of operation the slag that had accumulated on the side walls fused, ran down, and spread over the bottom of the furnace. The slag at the bottom of the furnace remained molten until the end of the test; then when the boiler was shut down to remove the slag from the tubes the slag at the bottom solidified and could not be removed with slice bars and hoe.

In boiler test 2 the slag at the bottom of the furnace of boiler No. 9 melted again after about two days' operation, and remained molten until the end of the test; the slag at the bottom of boiler No. 8 became soft and sticky and could not be removed while the boiler was in operation.

At the end of test 2, when boiler No. 9 was completely cooled down, men entered the furnace and removed the slag; it consisted of several layers 2 to 13 inches thick, totaling about 36 inches in depth.

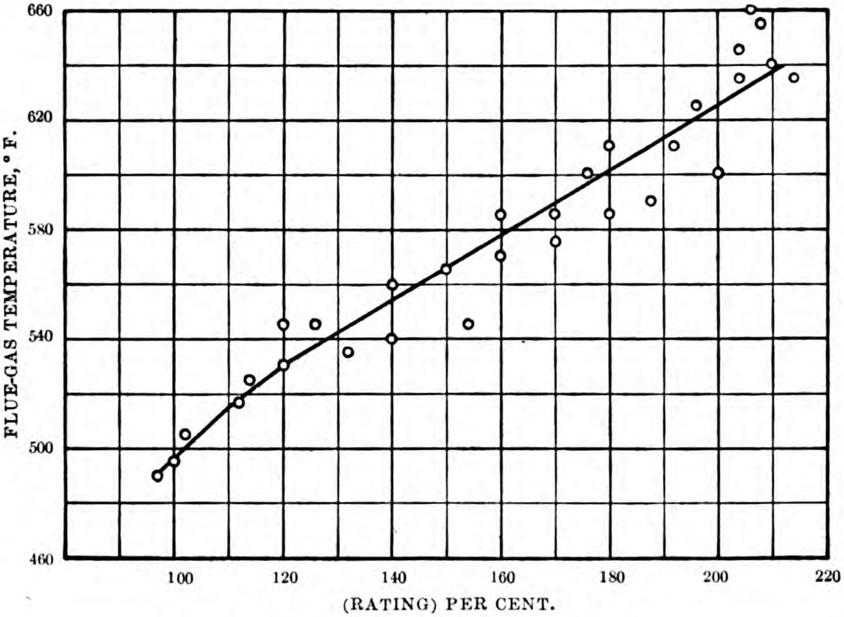


FIGURE 9.—Variation of flue-gas temperature with rating.

Boiler No. 8 continued in operation at the end of test 2. In an effort to direct currents of air through the cleaning-out doors against the bottom of the furnaces these doors were completely opened and steel plates, with their lower edges 3 to 4 inches from the bottom of the openings, were placed in the openings at an angle. This attempt to keep the bottom of the furnace cool was unsuccessful.

CONDITION OF FURNACE WALLS AT THE END OF THE TESTS.

At the end of test 2 the west wall about halfway up and the west half of the bridge wall of boiler No. 8 showed marked abrasion, more than at any other place in either boiler. The east wall and the bridge wall of boiler No. 9 showed considerable abrasion.

COAL PER REVOLUTION OF FEEDER.

Table 6 shows that the quantity of undried coal delivered at each revolution of the feeder was less than when dried coal was used. The undried coal evidently either packs less densely or adheres to the screw and so reduces the feed per revolution.

TABLE 6.—*Coal per revolution of feeder in tests at plant of St. Joseph Lead Co., Rivermines, Mo.*

Condition of coal.	Dried.			Undried.	
Test number	1	2	2	2	2
Part	......	1	2	3	4
Number of feeders in operation	4	8	8	8	8
Average revolutions per minute of feeders	95	66	70	85	87
Average weight of coal per mean revolution of feeder, pound	0.257	0.266	0.268	0.231	0.1991

RESULTS OF DRIER AND MILL TESTS.

The results of the mill tests are given in Table 7 and the results of the drier tests in Table 8. It should be remembered that the test conditions were rather unfavorable, owing to the many stops of the equipment during each test. By continuous operation better results could be obtained. With only two boilers in use, the capacity of the coal-preparation equipment is too high for maximum efficiency.

TABLE 7.—*Mill tests, St. Joseph Lead Co., Rivermines, Mo.*

1. Test number	1	2	3	4	5	6	7	8
Mill No. 1:								
2. Number of operating periods	4	5	10	5	10	7	5	7
3. Total time used in pulverizing ... hours	16.58	21.48	43.17	37.37	61.33	41.42	39.30	46.38
4. Actual running time of mill ... hours	7.5	7.07	11.87	8.58	31.03	17.45	27.32	29.48
5. Average current to mill motor ... amp	84	82	79	79	81	78	77	80
6. Power to mill motor ... kw	53.5	52.2	50.3	50.3	51.6	49.7	49.0	51.0
7. Average current to separator motor ... amp	35	35	37	37	37	37	37	37
8. Power to separator motor ... kw	22.3	22.3	23.6	23.6	23.6	23.6	23.6	23.6
Mill No. 2:								
9. Number of operating periods	2	5	12	4	10	5	6	4
10. Total time used in pulverizing ... hours	14.75	21.17	46.30	36.18	61.83	35.08	42.83	39.72
11. Actual running time of mill ... hours	8.83	6.92	15.85	8.47	26.83	17.78	22.83	19.30
12. Average current to mill motor ... amp	89	93	90	93	95	95	93	91
13. Power to mill motor ... kw	56.7	59.2	57.3	59.2	60.5	60.5	59.2	58.0
14. Average current to separator motor ... amp	35	35	37	37	37	37	37	37
15. Power to separator motor ... kw	22.3	22.3	23.6	23.6	23.6	23.6	23.6	23.6
Pulverized-coal conveyor:								
16. Actual running time of motor ... hours	9.50	8.80	16.13	9.53	32.98	18.10	27.90	30.73
17. Average current to motor ... amp	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
18. Power to motor ... kw	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5

TABLE 7.—*Mill tests, St. Joseph Lead Co., Rivermines, Mo.*—Continued.

1. Test number	1	2	3	4	5	6	7	8
Total and unit quantities:								
19. Total mill hours	16.33	13.99	27.72	17.05	57.86	35.23	50.15	48.78
20. Total coal pulverized ... pounds	194,970	146,700	292,500	204,500	658,100	401,500	432,700	396,700
21. Coal pulverized per mill hour ... pounds	11,940	10,490	10,550	12,000	13,370	11,400	8,630	8,130
22. Coal pulverized per mill hour ... tons	5.97	5.25	5.28	6.00	5.69	5.70	4.32	4.07
23. Average power to each mill ... kw	55.2	55.7	54.3	54.7	55.7	55.1	53.6	53.8
24. Average power to each separator ... kw	22.3	22.3	23.6	23.6	23.6	23.6	23.6	23.6
25. Total power for pulverizing operation ... kw	77.5	78.0	77.9	78.3	79.3	78.7	77.2	77.4
26. Average total energy for pulverizing operation per ton ... kw. h	13.0	14.9	14.7	13.1	14.0	13.8	17.9	19.1
27. Average energy for conveying from mills to bin per ton ... kw. h	0.3	0.4	0.4	0.3	0.3	0.3	0.5	0.5
28. Average total energy for pulverizing, separating, and conveying coal per ton ... kw. h	13.3	15.3	15.1	13.4	14.3	14.1	18.4	19.6
29. Moisture in coal as pulverized ... per cent	4.6	6.0	5.2	4.1	5.6	3.7	6.1	6.2
30. Coal dried or not dried	Dried.	Dried.	Dried.	Dried.	Dried.	Dried.	(1)	(1)
	Average for dried coal.						Average for undried coal.	
31. Total energy for pulverizing operation per ton ... kw. h	13.9						18.5	
32. Total energy for pulverizing, separating, and conveying per ton ... kw. h	14.3						19.0	
33. Coal per mill hour ... tons	5.6						4.2	

[1] Not dried.

TABLE 8.—*Results of drier tests.*

1. Test number	1	2	3	4	5	6
2. Number of operating periods	5	3	8	3	9	5
3. Actual running time, less 40 minutes per period ... hours	6.70	4.53	9.60	6.38	21.17	12.62
Coal:						
4. Total charged to drier drum ... pounds	194,971	147,933	295,200	204,500	658,117	401,447
5. Total burned for drying ... do	3,255	1,994	4,543	2,261	7,148	4,128
Proximate analysis and calorific value of coal to drier—						
6. Moisture ... per cent	8.5	8.7	8.4	6.5	8.4	4.6
7. Volatile matter ... do	32.4	31.9	32.8	32.5	30.7	32.2
8. Fixed carbon ... do	48.6	49.0	48.3	49.9	48.4	51.1
9. B. t. u. per pound	11,590	11,590	11,600	11,860	11,250	11,990
Proximate analysis and calorific value of coal from drier—						
10. Moisture ... per cent	4.6	6.0	5.2	4.1	5.6	3.7
11. Volatile matter ... do	33.1	32.1	33.4	32.8	32.2	32.4
12. Fixed carbon ... do	49.3	49.7	50.1	50.6	50.4	51.6
13. B. t. u. per pound	11,670	11,630	11,880	11,970	11,820	12,100
Temperatures:						
14. Coal from drier ... ° F	208	208	194	204	194	191
15. Gases to drier, average ... do	....	1,275	1,140	987	1,081	1,028
16. Gases to drier, minimum ... do	....	625	590	580	515	260
17. Gases to drier, maximum ... do	....	2,130	1,590	1,590	1,780	1,740
18. Gases from drier, average ... do	132	121	110	107	109	102
19. Gases from drier, minimum ... do	115	95	80	80	82	68
20. Gases from drier, maximum ... do	161	158	147	131	140	130
21. Room ... do	65	80	66	60	62	62
CO_2 in gases:						
22. To drier, average ... per cent	4.9	3.9	4.3	3.4	3.8	3.4
23. To drier, minimum ... do	2.4	1.2	2.0	1.6	1.0	1.0
24. To drier, maximum ... do	8.8	6.8	9.2	6.0	9.0	7.0

TABLE 8.—*Results of drier tests*—Continued.

Draft:						
25. At drier inlet ....inches of water..	0.08	0.10	0.06	0.06	0.06	0.08
26. At drier outlet..........................do....	0.40	0.42	0.39	0.39	0.41	0.45
Electric power:						
27. Average current to drier motor..........amp..	19.3	21.3	20.7	21.2	21.0	21.0
28. Average power to drier motor..............kw..	12.3	13.6	13.2	13.5	13.4	13.4
29. Average current to exhaust fan motor...amp..	6.5	6.5	6.5	6.5	6.5	6.5
30. Average power to exhaust fan motor......kw..	4.1	4.1	4.1	4.1	4.1	4.1
31. Average current to elevator motor.......amp..	4.4	4.4	4.4	4.4	4.4	4.4
32. Average power to elevator motor.........kw..	2.8	2.8	2.8	2.8	2.8	2.8
33. Average current to cross-conveyor motor.amp..	5.6	5.6	5.6	5.6	5.6	5.6
34. Average power to cross-conveyor motor...kw..	3.6	3.6	3.6	3.6	3.6	3.6
35. Average current to drier separator conveyor.................................amp..	4.2	4.2	4.2	4.2	4.2	4.2
36. Average power to drier separator conveyor.kw..	2.7	2.7	2.7	2.7	2.7	2.7
37. Total power for drying operation........do....	25.5	26.8	26.4	26.7	26.6	26.6
Rates:						
38. Coal charged per hour................pounds..	29,100	32,660	30,750	32,050	31,090	31,810
39. Coal burned per hour...................do....	486	440	473	354	338	327
40. Moisture evaporated per hour...........do....	1,181	931	1,052	803	920	307
Economic results:						
41. Moisture evaporated per 100 pounds coal charged.............................pounds..	4.1	2.9	3.4	2.5	3.0	1.0
42. Moisture evaporated per pound coal burned ....pounds..	2.4	2.1	2.2	2.3	2.7	0.9
43. Per cent heat in coal burned used to evaporate moisture......................................	23	19	21	20	26	8
44. Per cent heat in coal burned used to heat coal..	19	24	19	28	27	27
45. Per cent heat used for evaporation and heating coal (items 43 and 44)....................	42	43	40	48	53	35
46. Total electrical energy used per ton coal charged...............................kw. h..	1.75	1.64	1.72	1.67	1.71	1.67
47. Coal burned, in percentage of coal dried ....per cent..	1.7	1.3	1.5	1.1	1.1	1.0

CONCLUSIONS.

The results of the boiler tests, particularly of test 2, which lasted nine days under operating-load conditions, are very good when compared with stoker performance under similar conditions. The results of the tests also compare well with the results of the first group of 15 tests made at the Oneida Street Station, Milwaukee, Wis., with boiler No. 5, equipped with the original furnace and round burners. (See Bureau of Mines Bulletin 223.[1]) In this group of tests the average boiler efficiency was 78.8 per cent and the average rating was 114 per cent. The average CO_2 content of the flue gases was 12.6 per cent.

But the efficiencies in these tests are low as compared with the results of the tests made at the Lakeside Station, Milwaukee, which gave boiler efficiencies 7 to 8 per cent higher than the two Stirling boilers of the Rivermines plant gave. The reasons for the higher efficiency of the Lakeside plant are:

1. Special provision of water screen and air-cooled hollow walls, to prevent erosion of furnace lining and the slagging of the ash at the bottom of the furnace, which made possible the operation of the furnaces with a low excess of air.

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[1] This bulletin is not yet published, but the results of these tests may be seen in Transactions of the American Society of Mechanical Engineers, vol. 43, 1921, pp. 45–62. See also Blizard, John, Preparation, transportation, and combustion of powdered coal, Bull. 217, Bureau of Mines, 1922, pp. 74–76.

2. The four-pass boilers of the Lakeside plant are much better heat absorbers than the three pass boilers of the Rivermines plant, consequently the gases leaving the four pass boilers have a temperature about 130° F. lower than those from the Stirling boilers.

On account of these two features, the heat losses in the dry chimney gases of the Lakeside boilers are 7 to 10 per cent, whereas for the Rivermines boilers they are 12 to 15 per cent. For the hollow furnace walls of the Lakeside station the radiation losses are about 1½ per cent less than they are for the solid furnace walls of the Rivermines plant. The difference in these two losses nearly accounts for the difference in the efficiency of the two boiler plants.

When an attempt is made to operate the furnaces of the Rivermines plant with low excess of air and high CO_2 in the flue gases, the temperature in the furnace becomes so high that the ash at the bottom of the furnace melts and can not be removed while the furnace is in operation. The high temperature also causes excessive erosion of the furnace lining, because the melting point of the ash in the Illinois coal is so low that the ash melts completely at the high furnace temperatures, runs over the brick lining, and erodes the brick.

PUBLICATIONS ON THE COMBUSTION OF COAL IN BOILER FURNACES.

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BULLETIN 40. The smokeless combustion of coal in boiler furnaces, with a chapter on central heating plants, by D. T. Randall and H. W. Weeks. 1912. 188 pp., 40 figs.

BULLETIN 49. City smoke ordinances and smoke abatement, by S. B. Flagg. 1912. 55 pp.

BULLETIN 135. Combustion of coal and design of furnaces, by Henry Kreisinger, C. E. Augustine, and F. K. Ovitz. 1917. 140 pp., 1 pl., 45 figs.

BULLETIN 145. Measuring the temperature of gases in boiler settings, by Henry Kreisinger and J. F. Barkley. 1918. 72 pp., 31 figs.

BULLETIN 214. Tests of marine boilers, by Henry Kreisinger, John Blizard, A. R. Mumford, B. J. Cross, W. R. Argyle, and R. A. Sherman. 1923. (In press.)

BULLETIN 223. Powdered coal as fuel for power-plant boilers, by Henry Kreisinger and others.

TECHNICAL PAPER 80. Hand firing soft coal under power-plant boilers, by Henry Kreisinger. 1915. 83 pp., 32 figs.

TECHNICAL PAPER 137. Combustion in the fuel bed of hand-fired furnaces, by Henry Kreisinger, F. K. Ovitz, and C. E. Augustine. 1916. 76 pp., 2 pls., 21 figs.

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